Cathode-Coupled Converters for Surplus Receivers

A Single-Tube Crystal-Controlled Adapter for 28 Mc.

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• The fact that most surplus communications-type receivers do not cover the amateur 10- and 11-meter bands accounts, of course, for the current surge of interest in converters. In the one described here by W2EVI high-frequency stability is obtained through the use of a crystal-controlled fixed-tuned oscillator, while cathode coupling between converter and receiver is used as a means of simplification without sacrifice in performance. It requires no tuning control and only a single tube. Included also are suggestions for extending the principle to higher frequencies.

Having been so fortunate as to acquire at a bargain price a surplus Army receiver of the BC-779 (Super-Pro) variety, which tunes only as high as 20 Mc., I found myself face-to-face with the dire necessity of building a converter so that I could use the thing on ten meters. Thinking in terms of the orthodox type of converter, it occurred to me that it was a shame to have all that handsome conglomeration of radio parts, including two tuning dials, which comprised the BC-779, and then have to spend more time and money assembling more parts and dials, just to hear ten-meter signals.

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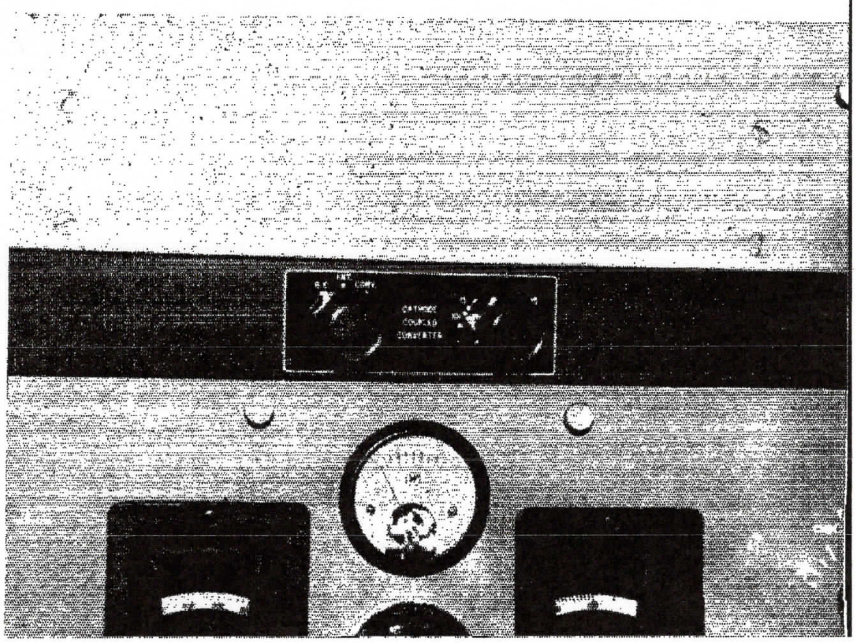
In order to take full advantage of the performance capabilities of the Super-Pro and not spoil the appearance of the operating position where it would be used, it would be necessary, if conventional design procedure were followed, to build a nice solid unit in a cabinet, with a good, expensive tuning dial. There is nothing I hate worse in a receiver than back-lash unless it is oscillator instability.

A bit of cogitation along these lines brought forth the not-entirely-novel idea of crystal controlling the converter oscillator and using the receiver as a tunable i.f. amplifier. This, it seemed, should eliminate the necessity for a fancy tuning dial on the converter, since only the relatively broad mixer grid circuit need be tuned from the front panel, and such an arrangement should provide the utmost in stability with the minimum of parts and constructional effort.

Design Considerations

The fundamental aim in designing this unit was, as indicated above, to provide as simple and compact a converter as possible, without sacrificing performance. It was recognized that the converter need contribute no gain, since the Super-Pro already had plenty, but that it should contribute a minimum of noise and spurious signals. Also, it had to work efficiently with the low-impedance receiver input as a load.

A conventional triode mixer circuit, as shown



The cathode-coupled converter for 10 and 11 meters installed above the receiver in a standard mounting rack.

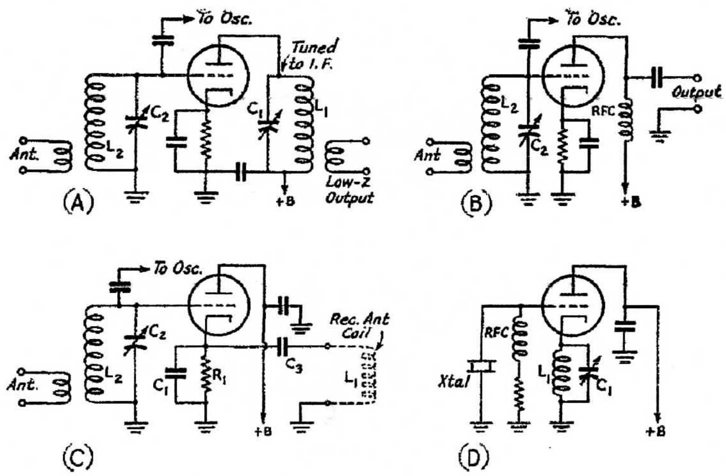


Fig. 1 — (A) — Conventional triode mixer circuit. (B) — Same as (A) with untuned output circuit. (C) — Cathode-coupled mixer circuit. (D) — Grid-plate crystal oscillator circuit.

in Fig. 1A, can give good performance, but it has the serious disadvantage that the plate circuit, L_1C_1, must be kept tuned to the same frequency as the variable i.f. amplifier. Substituting an r.f. choke for L_1C_1 as in Fig. 1B, also would work but the plate resistance of even a triode mixer would be so much higher than the load impedance which would result with this arrangement that it was feared a net loss in signal would result. A pentode mixer was not considered, by the way, because its greater gain was not needed, its signal-to-noise ratio is not so good as that of a triode, its higher plate resistance increases the difficulties mentioned in the preceding paragraph, and its additional elements would merely complicate the circuit.

The circuit which on paper looked to be the most promising, and certainly the most interesting, was the cathode-follower arrangement shown in Fig. 1C. To the best of my knowledge a cathode follower has not been used in this application before. According to the information available on cathode followers, this circuit should have the advantages of high input impedance, resulting in improved signal-to-image ratio, and some gain attributable to transformer action in the input circuit, because the circuit is not loaded. Also, it provides a low-impedance output circuit without the need for the transformer shown in the plate circuit of Fig. 1A. Actually, these advantages are obtained, but the situation is more complicated than it appears because of the presence of reactance in the cathode load circuit.

If we redraw Fig. 1C with a crystal in place of the grid coil-condenser circuit, and a condenser C_1 in parallel with the receiver antenna coil, L_1, as in Fig. 1D, we recognize a simplified version of our old friend the grid-plate crystal oscillator.[1] The tube doesn't care whether the resonant circuit between its grid and plate (remember, the plate is by-passed to ground) is a crystal or a coil and condenser and, of course, it is impossible not to have some capacitance across L_1. If the combination of the capacitance and inductance at L_1C_1 happens to present a capacitive reactance of the proper value to the cathode, or in other words if L_1 and C_1 in parallel tune to a frequency somewhat lower than L_2 and C_2, the circuit will oscillate.[2] In most practical cases this is exactly what happens.

Let us not despair, however. Remember the "if" — L_1C_1 must tune to a lower frequency than L_2C_2 in order to promote oscillation. But, as shown graphically in Fig. 2, if we tune L_1C_1 low enough the circuit stops oscillating and becomes merely regenerative. It is also apparent from Fig. 2 that oscillation can be prevented by tuning L_1C_1 to the same frequency or to a higher frequency than L_2C_2, but in most cases this will be difficult or impossible. Furthermore, if L_1C_1 looks inductive at the frequency of L_2C_2, degeneration results, with consequent loss of performance.

By deliberately adding capacitance to whatever stray capacitance may exist at C_1, we are able not only to stop oscillation but also to control the amount of regeneration present. The more regeneration, short of oscillation, the more gain and selectivity (and noise). Fortunately the value of C_1 is not critical.

The Converter

The unit shown in the photographs was, of course, built to suit my own particular requirements. Certain specific features of it, such as its physical dimensions and the use of single-ended input and output circuits, may not suit the needs

[1] *Radio Amateur's Handbook*, ed. 23, p. 98.

[2] Schlesinger, "Cathode-Fellower Circuits," *Proc. I.R.E.*, Dec., 1945, p. 849.

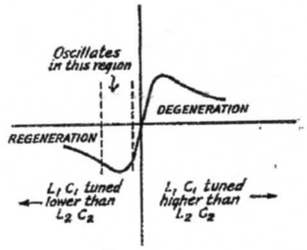


Fig. 2 — Curve showing effect of tuning cathode tank circuit above and below frequency of grid circuit.

of all hams, but the circuit shown in Fig. 3 should work with any receiver and, in fact, it has been tested with several different types.

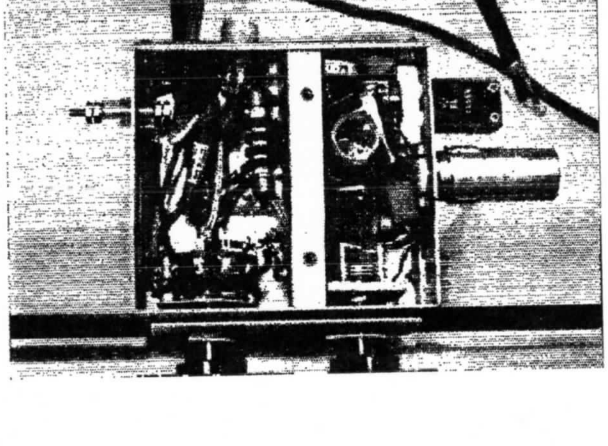
As shown in the photographs, the converter is mounted on a 1¾-inch panel which, in turn, mounts between the receiver and its power supply in a small table rack. On the front are two controls — the mixer grid tuning and a three-position rotary switch whose purpose is explained later. On the back are the coaxial-connector socket for the antenna input and the adjusting nut for the oscillator tuning condenser, C_3. On the left side is a feed-through insulator used for connecting a spare indoor antenna to the receiver in case break-in is desired, or for reception on the low-frequency bands. The crystal and tube are on the right side where they are convenient for replacement and are properly ventilated.

It was obvious from the start that shielding would be an important problem with this arrangement, and experience with an experimental model emphasized the point. Therefore the entire unit was enclosed within an aluminum box which was battered into the desired size and shape with the aid of tin snips, hammers, files, etc. The aluminum partition through the center is intended to prevent undesired signals at the i.f. from being coupled to the converter circuit from the various input circuits. A 1¼-inch hole was cut in this partition with a socket punch, and a small Faraday screen mounted across the hole on a strip of polystyrene. The grounded end of L_2 butts against one side of the screen, and the antenna coil, L_1, is mounted on terminal lugs on the other side. The Faraday screen, of course, is intended to prevent capacitive coupling of stray signals to the mixer circuit, without affecting the inductive coupling between L_1 and L_2.

It was feared originally that shielding of the crystal holder and perhaps the adjusting nut on C_3 would be necessary, since both are connected to the antenna post of the i.f. receiver, but this was found to be unnecessary when using an i.f. of 3 to 4.7 Mc. With an antenna tuned to ten meters coupled to the converter, and the converter oscillator disabled, it is possible to tune the i.f. receiver from 3850 kc. to 4000 kc. in the evening without hearing the faintest suggestion of a signal. However, touching a finger to the ungrounded antenna terminal on the i.f. receiver produces S9 signals anywhere in that range. With an antenna tuned to 75 meters connected to the converter, weak signals can be heard in this range. After some experimentation I concluded that this was not an indication of poor shielding, but simply proof of the fact that the skirts of the response curve of L_2C_2 are not down to zero response even at 25 Mc. from resonance.

As the i.f. receiver is tuned higher in frequency, more signals are heard "leaking" through the converter, which is one reason I chose to use the 3–4.7-Mc. range. Experimentation indicates that this "leakage" is caused by both insufficient shielding and insufficient selectivity of L_2C_2. Since I didn't intend to use these higher intermediate frequencies, I made no attempt to improve the situation, but I mention the point to emphasize the need of great care in shielding. Still further, I found that touching the metal shaft on C_2 would sometimes increase the strength of the signal "leaking" through. This means that at high frequencies the condenser shaft is not adequately grounded, even though the lead grounding it is not over an inch long. If considerably higher intermediate frequencies were used with this unit it might be necessary to mount C_2 completely within the shielding and use an insulated shaft extension to prevent the shaft from acting as an unwanted antenna. The leads from S_{1A} to the antenna-input connector, and from S_{1B} to the 6J6 cathode, are shielded to prevent undesired signals from taking a short-cut from the antenna lead right into the i.f. receiver.

As shown in the circuit diagram of Fig. 3, S_1



Top view of the crystal-controlled 28-Mc. converter. The antenna-input section is to the left, separated from the mixer grid and oscillator circuits by the shielding partition.

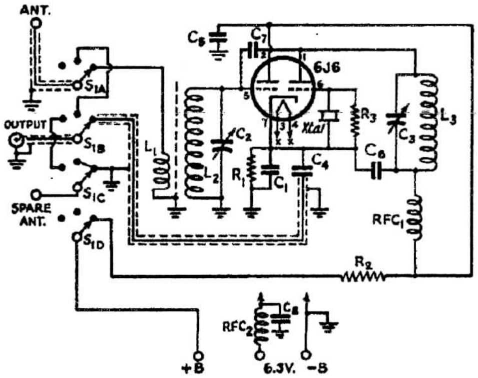


Fig. 3 — Circuit diagram of the single-tube cathode-coupled converter for 28 Mc.

C_1 — 100-μμfd. mica.
C_2 — 15-μμfd. variable (Millen 20015).
C_3 — 25-μμfd. variable (Hammarlund APC-25).
C_4, C_8 — 0.001-μfd. mica.
C_5, C_6 — 470-μμfd. mica.
C_7 — Coupling condenser, see text.
R_1 — 4700 ohms, ½ watt.
R_2 — 0.1 megohm, 1 watt.
R_3 — 0.1 megohm, ½ watt.
L_1 — 2 turns No. 18, ¾-inch diameter.
L_2 — 14 turns No. 24, ¾-inch diameter, 1 inch long.
L_3 — 10 turns No. 24, ¾-inch diameter, ¾ inch long.
RFC_1 — 2.5-mh. r.f. choke.
RFC_2 — Ohmite Z-1 r.f. choke.
S_1 — Poles of four-section 3-position rotary switch.

is a three-position four-pole rotary switch. In the clockwise position of S_1, the center conductor of the antenna-input connector is connected to L_1, the center conductor of the short length of coaxial cable which is used for the output cable to the i.f. receiver is connected to the cathode of the 6J6 through condenser C_4, while B+ is connected to the converter plates. In the middle position the center conductor of the antenna connector is connected to the center conductor of the output cable, and B + is removed from the converter. This position is used for normal operation of the Super-Pro without the converter. In the counter-clockwise position the center conductor of the output cable is connected to the spare antenna feed-through terminal which, by the way, is grounded in the other two positions of S_1 to remove another possible source of our old enemy, the undesired signal. This last may be an unnecessary refinement, but the switch I found in my junk box had four poles, so I figured I might as well use the extra pole for something. This switch need not have ceramic insulation because it switches only low-impedance r.f. circuits.

The counterclockwise position of S_1 is provided because an indoor antenna works better on the broadcast band than my transmitting antennas, but this switch position also could be used for break-in or duplex operation, or any other occasion when an extra antenna is desired. And before some BC-779 owner has a hemorrhage from this discussion of broadcast-band reception, let me explain that my particular receiver has been promoted to the rank of BC-1004, first class. In other words, I obtained from the Hammarlund Company a set of coils, dials, knobs, etc., with which I altered the original 100–400-kc. tuning range to the more useful one of 540 to 2500 kc. This also explains, in case anyone wonders, how I am able to receive the 11-meter band with a 25-Mc. crystal frequency in the converter, which requires tuning the receiver from 2160 to 2450 kc.

The tuning range of the coil and condenser shown, L_2 and C_2, is approximately from 21 to 30 Mc., taking in all of the 10-, 11- and 15-meter bands. Even with this large coverage, adjustment of C_2 is easy, provided that the amount of regeneration in the mixer is kept within reason. The value of condenser shown at C_1 gives a degree of regeneration which results in an apparent signal gain of 8 or 10 db. with reasonably uncritical tuning of C_2 when the converter is feeding into a Super-Pro receiver tuned to 3 Mc. If some other receiver is used for the i.f. it will probably be necessary to experiment with different values of C_1 to obtain optimum results, since the receiver antenna-coil inductance will be different. Some military receivers, such as the BC-342, have a variable condenser in series with the antenna coil which must be adjusted for optimum results when using this converter.

To tune from 21 to 21.5 Mc., the i.f. receiver is tuned from 4 to 3.5 Mc. Putting the oscillator frequency between the major bands to be covered in this manner has the advantage of keeping the i.f. low, thereby reducing "spurious-signal" trouble and also makes the operation of changing bands quite simple. But it has the disadvantage of causing images of the ten-meter band to fall in the 15-meter band, and vice versa, and means that one must tune the i.f. receiver higher in frequency to receive a signal lower in frequency in the 15-meter band, which may prove confusing. The relative importance of these advantages and disadvantages can best be determined when and if we get a fifteen-meter band. Under present conditions the 25-Mc. oscillator frequency works out very well.

RFC_2 and C_8 are intended to reduce a weak spurious signal that results from a beat between the converter oscillator and a harmonic of the receiver oscillator. The two frequencies are coupled together through the heater supply in my case, but this condition might not arise at all with other makes of receivers.

The crystal oscillator is the conventional tuned-plate crystal-grid circuit, using the second half of the 6J6. The grid and plate circuits are returned directly to the cathode, and RFC_1 prevents C_5 from shunting C_1. The value of R_2 was determined by reducing the plate voltage while listening to a very weak signal. As R_2 was

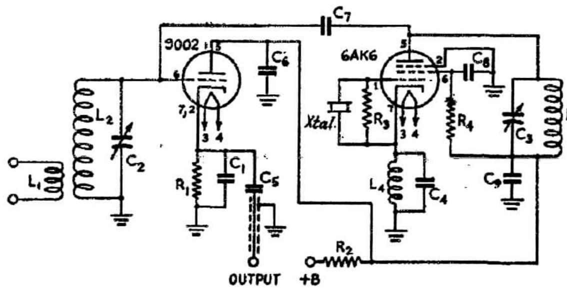


Fig. 4 — Suggested circuit for cathode-coupled crystal-controlled converter for higher frequencies.
C_5, C_8, C_9 — 0.001-μfd. mica.
C_6 — 470-μμfd. mica.
R_1 — 10,000 ohms.
R_2 — 22,000 ohms.
R_3 — 0.47 megohm.
R_4 — 4700 ohms.
Other values will depend upon frequency.

increas ınd the plate voltage went down, the noise lc went down while the signal stayed the same a became more readable. Strong signals became ightly less strong as the voltage was reduce ut that did not seem disadvantageous. The va ‹ shown for R_2 is about the practical limit w a 250-volt supply. Further increase in resista: reduces weak-signal strength with no furthei provement in signal-to-noise ratio.

The cillator coupling condenser, C_7, is a "gimı " — a short length of insulated wire from t... ›scillator plate wrapped once around the mixer grid lead.

Notes & Comments

Before building a converter of this type, it would be wise to tune the receiver with which you intend to use it over the i.f. range you intend to use at a time when strong signals are present in that range, and with no antenna on the receiver. If you hear signals give up the whole idea, because the receiver is not sufficiently well shielded. Probably most communications receivers will pass this test, however.

The choice of an oscillator crystal frequency depends on a wide variety of factors, not the least important of which is what is available. One reason for my choice of 25 Mc. was that a number of crystal manufacturers advertised crystals in that range for doubling to the 6-meter band. After writing to one after another of these manufacturers, and having them all reply that they did not manufacture such an item (apparently they don't read their own ads) I was ready to give up when finally the Valpey Company ran a similar ad, and I decided to try once more. Much to my astonishment, I got a crystal for 25,008 kc., which is close enough.

An oscillator frequency which is an even multiple of 1000 kc. is convenient, because it is then easy mentally to add the oscillator frequency to the i.f. indicated on the receiver dial and come out with the frequency being received. For instance, when my Super-Pro dial reads 3.6 Mc., I automatically translate that to 28.6 Mc. This works only when the oscillator is lower than the signal frequency, of course; on 15 meters it will be necessary to subtract which is not so convenient.

Other considerations in choosing an oscillator frequency are: (1) fundamental and harmonics of the oscillator should not fall within the bands to be covered by the converter nor within the range to be covered by the i.f. receiver; (2) resulting intermediate frequencies should not contain extremely-strong local signals (this rules out the broadcast band in some locations), but should preferably be fairly low since this simplifies shielding and associated "spurious-signal" problems; (3) resulting intermediate frequencies for any one band should all fall in one tuning range of the i.f. receiver. It would be annoying to have to switch coils to cover both ends of the ten-meter band, for example.

So far as I am able to tell without elaborate test equipment, the sensitivity and signal-to-noise ratio resulting from this receiver-converter combination are as good as is normally obtained with a good communications receiver on ten meters.

With the i.f. in the 3–5-Mc. range, attenuation of i.f. "spurious signals" is apparently (no test equipment again) better than 70 db., and attenuation of images is around 35 db. As mentioned previously, the antenna used for receiving can contribute a surprising amount of useful selectivity. The above attenuation figures are based on observations made on ten meters with a 75-meter half-wave center-fed doublet, with feeders tuned to resonate in the ten-meter band. Using a center-fed ten-meter half-wave antenna, much better attenuation figures have been obtained. In any

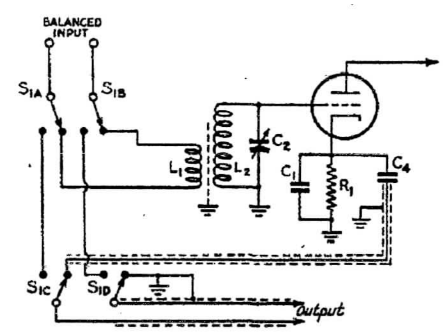
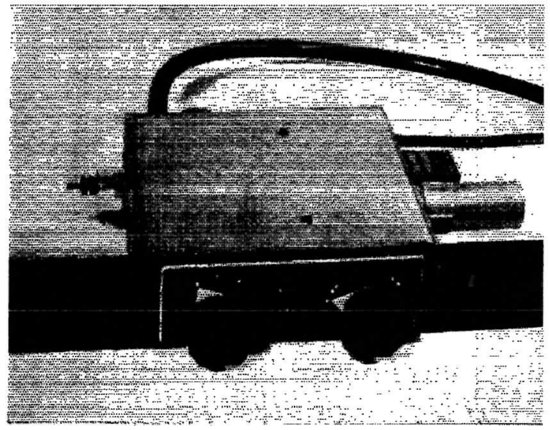


Fig. 5 — Suggested circuit for balanced input to converter. $S_{1A\text{-}D}$ are poles of a four-pole double-throw rotary switch. Other designations are similar to those of Fig. 3.



Panel view of the cathode-coupled converter with top cover in place.

case, the figures given compare favorably with image-rejection ratios of standard communications receivers on ten meters.

Theoretically, a better signal-to-noise ratio could be obtained with a tube having separate cathode terminals for the two triode sections, because the oscillator plate current would then not have to flow through the cathode load resistor, R_1, thus contributing to the noise, but not to the signal. A new miniature type, the 12AU7, has just been announced which should be ideal for the purpose.

The addition of a 6AK5 tuned r.f. stage ahead of the mixer in this unit should result in a receiving combination with very superior performance at 10, 11 and 15 meters. While this would not be entirely in keeping with my original objective of extreme simplicity, it should not complicate the tuning-control problem, since the additional gain would make it possible to reduce the regeneration in the mixer thus, in turn, reducing the sharpness of the mixer tuning. The net sharpness of tuning near resonance then should be about the same as without the r.f. stage, but the rejection of signals far removed from resonance would be greatly increased, resulting in complete solution of the image and "spurious-signal" problems. At the same time the best signal-to-noise ratio theoretically possible should be obtained. I do not intend to add an r.f. stage to my unit because I feel that its present performance is quite adequate, but I mention the point for the benefit of those who seek perfection.

Variations on the Theme

During the many months when I was searching for a 25-Mc. crystal, I used an experimental converter the circuit of which is shown in Fig. 4. The principle feature of this circuit is the Tri-tet crystal oscillator which permits the use of a lower-frequency crystal. In my case the crystal frequency was 5.5 Mc., and the plate of the Tri-tet was tuned to the fourth harmonic, or 22 Mc. This circuit should be particularly useful in extending the range of existing ham receivers to include the 6-meter band, or even the 2-meter band. The choice of a crystal frequency for this circuit is affected by all the previously-mentioned factors, plus the fact that spurious responses can result from beats between undesired signals and harmonics of the crystal frequency other than the one you are intending to use. If, for example, you are trying to use the tenth harmonic of a 4-Mc. crystal to give an i.f. range of 10 to 14 Mc. for the 6-meter band, you will very likely find that there is enough 44-Mc. (11th harmonic) energy in the Tri-tet plate tank to give you a whopping big signal in the middle of the band from your local television station operating in the 56–60-Mc. channel. This effect can be minimized by using a low L/C ratio in the Tri-tet plate tank, but the best solution is not to go above the fourth or fifth harmonic of the crystal. This still permits 2-meter operation using crystals at 25–30 Mc.

If the single-ended input and output circuits shown do not fit in with your favorite antenna-feeder system, it should be possible to use a balanced input system with little difficulty. One possible circuit is shown in Fig. 5. Note that one side of the receiver input is grounded when the converter is in use, since the converter output must be single-ended, but that the antenna input circuit remains balanced at all times.

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